29th International Cosmic Ray Conference Pune (2005) **2**, 409-412

CORONAS-F observations of solar energetic protons: changes of geomagnetic transmissivity in the disturbed magnetosphere

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The geomagnetic transmissivity for cosmic ray vertical access is computed for selected intervals of disturbed magnetosphere using two geomagnetic field models. The improved transmissivity of the magnetosphere lead to the increases observed at neutron monitors at stations with middle and high cutoff nominal position. During the October 29, 2003 solar flare event, the increase of proton intensity >75 MeV at CORONAS-F satellite at L=3 coincided with the cutoff reduction expected by Dst depression. The increase of protons >75 MeV at L=3 was observed also during the magnetospheric disturbance on November 8, 2004 during the geomagnetic disturbance when rather strong cosmic ray decrease was observed on the ground as well as on high latitude passes of CORONAS-F.

1. Introduction

Access of low energy cosmic rays to the Earth is controlled by the geomagnetic field. This effect is usually estimated by particle trajectory tracing from the point of observation in the model geomagnetic field (e.g. [1]). The computational results are compared with the measurements both on ground based cosmic ray observations (e.g. [2, 3] among others) as well as on low altitude satellite ones (e.g. [4-6]). During the enhanced geomagnetic activity the changes of cutoffs and of asymptotic directions occur (e.g. [7]).

Here we present computations of the geomagnetic transmissivity for selected recent periods with strongly disturbed magnetosphere, and illustrate the increases of solar cosmic rays and low energy galactic particles observed on the ground and on CORONAS-F satellite due to the improvement of transparency of magnetosphere. In addition to the models used earlier the computations here are done also with a new model [8], where input data are available.

2. Transmissivity at two approaches: ground based observations

We use a method, similar to earlier ones (e.g. [1]), tracing the cosmic ray particle trajectory from a given point on the Earth's surface with the reversed charge sign and velocity vector and numerically solving the equation of motion in the model field **B**. The details of the computation method and dependence of the result on parameters of computations can be found in [9-11]. For **B** we use the modified Geopack 2003 subroutines (http://nssdc.gsfc.nasa.gov/space/model/magnetos/data-based/modeling.html) based on IGRF model (http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html). The IGRF coefficients up to order/degree 10 are used. Upper and effective cutoffs are computed according to the definitions by [12]. The transmissivity here is defined as the probability that a particle having rigidity R will access the detector from zenith direction (vertical access).

During the large decrease of Dst on November 20, 2003, the transmissivity of magnetosphere was strongly enhanced which lead to the increase of cosmic ray intensity clearly seen at European stations with higher nominal cut-off (Figure 1 left). We performed the computations using two approaches: (1) Tsyganenko Ts89 model with Dst extension [13] and (2) the new Tsyganenko TS04 model [8]. The profiles of vertical cutoffs before the storm onset and during minimum Dst for the two models are seen in Fig. 1 right for Rome. For this particular interval the timing of minimum cutoff is better corresponding to the increase at NM Rome for TS04 model than for Ts89+Dst extension. For the approach (2) the vertical cutoff reduction is smaller than for the approach (1).

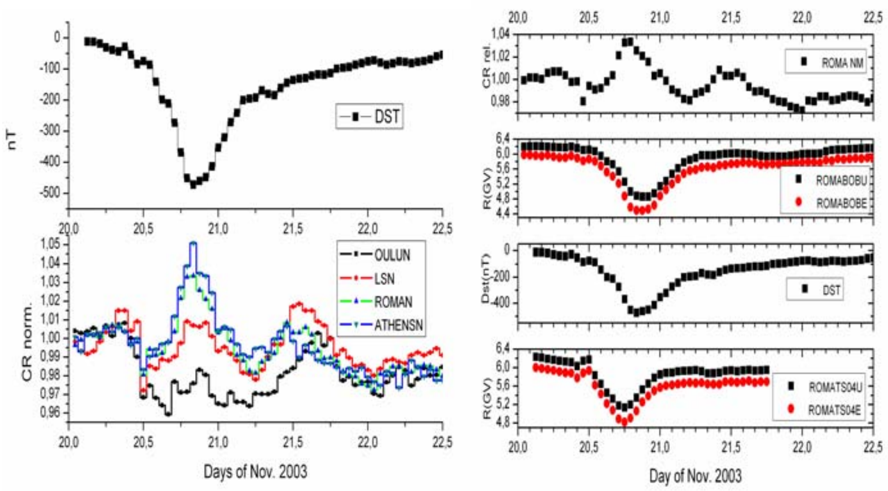

Figure 1. Left: Neutron monitor time profiles at 4 European stations (Oulu - OULUN, Lomnický Štít - LSN, Rome - ROMAN, Athens - ATHENSN) during the Dst decrease on November 20-21, 2003, normalized to the mean 00-12 UT on November 20. Right: The vertical cutoffs computed for the approach (1) (ROMABOBU – upper, ROMABOBE – effective) and approach (2) (ROMATS04U – upper, ROMATS04E – effective) of geomagnetic field model.

3. Transmissivity during two events: CORONAS-F observations

One of the instruments on low altitude, polar orbiting satellite CORONAS-F is SONG dedicated for measurements of high energy gamma rays and neutrons from the Sun (description in paper [14]. Along with that the scintillator detector provides the measurements of protons with energy >75 MeV and electrons >40 MeV. It has a large geometrical factor (2000 cm^2, channel 1 in the following). This allows to measure on the orbit the variations of low energy cosmic rays especially during the solar flare events. Another energetic particle experiment is MKL. We use here data from both. At earlier experiment on CORONAS-I we have shown the decreases of galactic cosmic rays can be observed with similar instrument at the channel with even higher energies [15]. SONG on CORONAS-F has one more high energy channel, namely for protons Ep=200-300 MeV (channel 2).

Figure 2 shows the time profile of measurements by SONG instruments (channel 1) at the crossings of L=3 along with the measurements of protons 50-90 MeV observed at MKL instrument (not saturated) at high latitudes during the interval October 28-31, 2003. The largest increase at L=3 by MKL and SONG (>75 MeV) approximately corresponds to the lowest Dst and to lowest cutoffs expected. Contrary to that case, the solar flare with high energy protons on November 2-4, 2003 when no significant geomagnetic activity was present, did not yield into the increase of protons at L=3 as shown in Figure 3.

While for the interval October 28-31, 2003 there were no data for the input into TS04 model, for the second interval analyzed here, namely in November 7-12, 2004, the data are available. There was observed rather complex, long lasting decrease in cosmic rays shown in Fig. 4. The recovery of CR intensity observed on the ground to the prestorm level was reached close to the end of November (at Lomnický Štít and also at Oulu NM). Cosmic ray intensity below the atmospheric threshold (channel 1 at SONG/CORONAS-F) is still depressed.

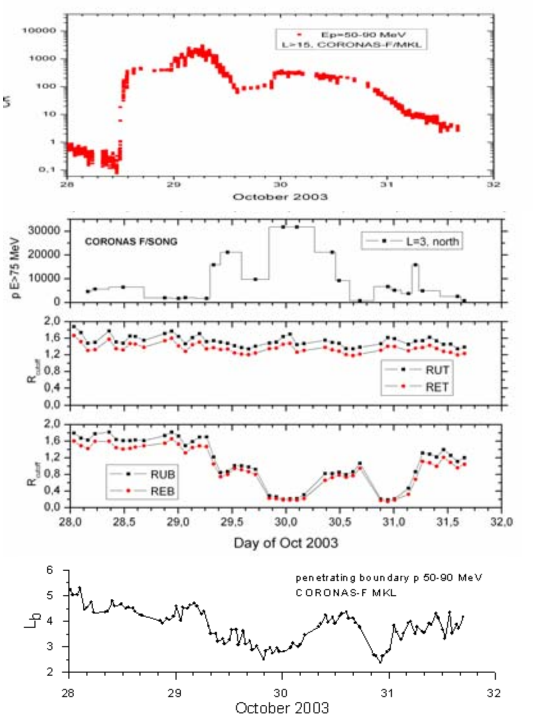

Figure 2. The event on October 28 seen at high latitudes (L>15 selections, upper panel) and at L=3 in the northern hemisphere (2nd panel from top). The two next lower panels show the expected vertical cutoffs for Ts89 [16] (RUT - upper, RET - effective) and Ts89+Dst [13] (RUB - upper, REB - effective).

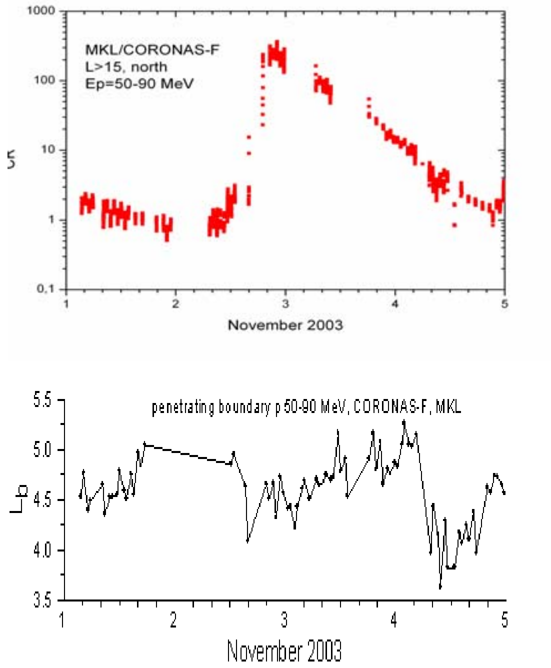

Figure 3. The event on November 2-4, 2003 observed at high latitudes (upper panel) on CORONAS-F was not accompanied by the increase of energetic protons to L=3 (lower panel shows the boundary of proton penetration).

During the geomagnetic disturbance on November 8, 2004 the transmissivity of magnetosphere increased. One signature of that is seen at Lomnický Štít. It was better pronounced again at Rome and at Athens NM (not shown here). There was a moderate increase of proton flux with the maximum around the midnight 07/08 November observed at GOES. The Dst was decreasing to -345 nT at 06 UT on November 8. During the Dst decrease the channel 1 of SONG indicated increases at L=3 and slight one at L=2. The computations of vertical cutoffs were done using both approaches. The profiles at L=3 along with the cutoff expectations on CORONAS-F orbit are presented in Figure 5. Although the increase of counting rate corresponds to the interval when cutoffs are expected to be < 1 GV, its maximum does not match exactly the minimum of cutoffs. Contrary to the first case when the changes of both cutoffs were much stronger for Ts89+Dst approach than for TS04 one, here the differences are not significant.

4. Summary

The vertical cutoffs were computed using (1) Tsyganenko 1989+Dst extension geomagnetic field model and (2) Tsyganenko 2004 dynamical model, for three intervals when magnetosphere was strongly disturbed. For November 20, 2003 disturbance the approach (2) provides more moderate shifts of vertical cutoffs than (1) for ground-based stations. Penetration of solar protons to CORONAS-F orbit at L=3 during the solar proton event on October 28-29, 2003 was observed due to the improvement of magnetospheric transmissivity. For

November 2-4, 2003 event without significant geomagnetic activity, the increase at L=3 was absent. During the geomagnetic disturbance on November 8, 2004, the increase of >75 MeV protons due to the depression of vertical cutoff was observed at L=3, too.

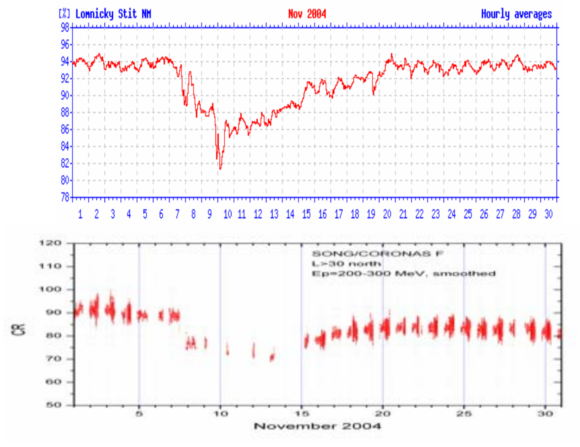

Figure 4. Cosmic ray decrease observed on CORONAS-F and at Lomnický Štít neutron monitor during the interplanetary and geomagnetic disturbances in November 2004.

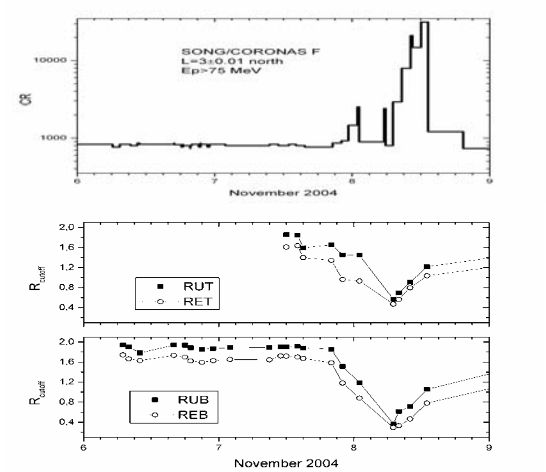

Figure 5. Count rate of the channel 1 SONG at CORONAS-F at the crossings of L=3 (upper panel) and computed vertical cutoffs for the two models of geomagnetic field (T – TS04, B – Ts89+Dst).

5. Acknowledgements

Work of KK and RB was supported by VEGA grant 2/4064.

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